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RELIABILITY IMPROVEMENT WARRANTIES FOR MILITARY PROCUREMENT.(U)
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December 1977

Reliability Improvement Warranties for Military Procurement

Arturo Gándara and Michael D. Rich

A Project AIR FORCE report
prepared for the
United States Air Force

Rand
SANTA MONICA, CA. 90406

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Library of Congress Cataloging in Publication Data

Gándara, Arturo, 1944-
Reliability.

([Report] - Rand Corporation ; R-2264-AF)
1. United States--Armed Forces--Procurement.
2. Weapons systems--Reliability. 3. Defense contracts--United States. 4. Warranty--United States.
I. Rich, Michael D., joint author. II. United States. Air Force. III. Title. IV. Series: Rand Corporation. Rand report ; R-2264-AF.
AS36.R3 R-2264 [UC263] 081s [355.6'212'0973]
ISBN 0-8330-0006-3 78-4044

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-2264-AF	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Reliability Improvement Warranties for Military Procurement.		5. TYPE OF REPORT & PERIOD COVERED 9 Interim rept., 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. Gandára and M. D. Rich		8. CONTRACT OR GRANT NUMBER(s) 15 F49620-77-C-0023
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Rand Corporation 1700 Main Street Santa Monica, Ca. 90406		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Project AIR FORCE Office (AF/RDQA) Directorate of Operational Requirements Hq USAF, Washington, D.C. 20330		12. REPORT DATE 11 December 1977 13. NUMBER OF PAGES 56
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 10 Arturo/Gandara Michael D./Rich		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for Public Release; Distribution Unlimited 12 67p.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) No restrictions		
18. SUPPLEMENTARY NOTES 14 RAND/R-2264-AF		DDC RECEIVED JUL 3 1978 E
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Reliability Quality Assurance Warranties Armed Forces Procurement Acquisition		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) see reverse side		

296 600

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Examines the Reliability Improvement Warranty (RIW). Consumer and commercial warranty experience does not alone justify optimistic expectations for RIWs; the effect of RIWs in completed DoD programs is inconclusive; and as a result of inadequate research design the expectation of drawing meaningful conclusions from the ongoing RIW experiment may be over-optimistic. Examination of completed RIW programs, however, suggests the importance of (1) modification after operational use or testing, (2) schedule flexibility, (3) contractor involvement in initial overhaul and repair, (4) and avoidance of RIWs in programs subject to extreme quantity or utilization uncertainty. The design of the DoD's ongoing RIW experiment can be improved by (1) reducing the variation in contractual terms, (2) developing better controlled conditions, and (3) establishing defined limits for the experiment. In addition, the DoD must recognize the multiple objectives of the RIW and establish priority among them to facilitate evaluation. (Author)

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PREFACE

One of the recent attempts to use a contractual device to manage advanced technology weapon system acquisition is the Reliability Improvement Warranty (RIW). The RIW's effects on project outcomes and its preferred form are still not well understood. The Department of Defense hopes that the RIW will improve the reliability and reduce the life cycle cost of its weapon systems. This report describes the accumulated experience with warranties in both commercial and military settings. It should be of interest to the development, acquisition, logistics, and contracting communities of all branches of the Department of Defense.

This research was initiated by Rand, and was jointly sponsored by two Project AIR FORCE programs: Systems Acquisition Management (project: System Acquisition Policy Studies) and Operations and Readiness Improvements (project: Methods and Applications of Life Cycle Analysis for Air Force Systems).

SUMMARY

One of the devices aimed at improving reliability of weapon systems and reducing their life-cycle costs now being studied and tested by the U.S. Department of Defense (DoD) is the Reliability Improvement Warranty (RIW). Under an RIW, a contractor assumes responsibility on a fixed-price basis for repairing or replacing (as he sees fit) warranted units that fail during the warranty period. (A variation combines the warranty with a guarantee that obligates the contractor to take whatever steps are necessary to meet specific reliability levels.) This report explores the RIW concept by evaluating commercial analogs, past DoD warranty experience, and current trial RIW applications.

In August 1974, various parts of the Office of the Secretary of Defense requested tri-service experimentation with RIWs. At that time military experience with warranties was scant, but commercial experience was widely regarded as promising. In fact, however, from the buyer's perspective commercial experience does not justify optimistic expectations for RIWs. The purpose of consumer product warranties has usually been either promotional or protective--they have either been marketing tools or devices to limit liability. They rarely improved product quality.

Commercial airline avionics, which usually carry warranties, appear at first sight to be generally more reliable than similar equipment used by the military services. However, there are too many differences in the commercial and military worlds--e.g., in definitions, mission requirements, operating and support environments, and data systems--to credit the better reliability to the warranties.

The effect of the warranties in completed DoD programs is largely unclear. The Navy's APN-154 Beacon experienced improved reliability, but the improvement is traceable to *pre-warranty* redesign and externally generated component technology advancements, not to the warranty. Another item, the Navy's 2171 Gyro, also improved significantly, but such improvement may have been obtainable through effective use of increased testing apart from the warranty program, perhaps at less cost. In the other completed warranty program, the Air Force's F-111 Gyro, units

under warranty were more reliable than units purchased previously without a warranty. The warranty was not clearly responsible for the improvement though. Because the number of warranted units purchased was severely reduced and those that were purchased were used far less than expected, the contractor made only one minor design improvement during the warranty period. The warranted units' reliability is explained by their having been manufactured by a different contractor than the nonwarranted units, selected in a competitive environment, and subjected to substantial failure mode testing before delivery.

Although it did not conclusively prove that warranties were a major factor in the observed results, examination of the three completed DoD warranty programs does permit the following observations:

- Modification after some operational use of appropriate operational testing is almost always desirable to take advantage of field experience and advances in component state of the art and can be promoted without a warranty.
- Implied in the above statement is the worth of schedule flexibility in the program to allow incorporation of test data in the subsequent development and production process.
- To the extent that modification is envisioned or desired, it may be valuable to involve the contractor in the initial overhaul and repair activities so it will be better able to formulate product improvements.
- Because the prospect for reliability growth is dimmed by program quantity reductions and underutilizations, RIWs should not be applied to programs subject to extreme quantity or utilization uncertainty.

There are many current experimental applications of the RIW concept, and conclusions about the value of RIWs should probably await their results. The warranty periods of the current programs end in the early 1980s, but possible new trial applications are still being reviewed so the data may not be complete until the mid-1980s. More important, expectations of the ability to draw conclusions from current experiments may be overoptimistic.

ACKNOWLEDGMENTS

For insightful comments on early drafts of this report, the authors are grateful to Rand colleagues Geneese Baumbusch, Frank Camm, C. Cullinan-James, Edmund Dews, Giles Smith, and Richard Victor, and to Colonel Robert Ziernicki, head of the Avionics Division, Directorate of Development and Acquisition, Office of the U.S. Air Force Deputy Chief of Staff (Research and Development). Special appreciation is due David Newman of the Directorate of Procurement Policy, Office of the U.S. Air Force Deputy Chief of Staff (Systems and Logistics) for assistance during both the research and report preparation phases of this study.

Bernadine Siuda and Sandy Edwards skillfully prepared the manuscripts at all stages of the study.

The authors are responsible for any remaining errors of fact or interpretation.

CONTENTS

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ABBREVIATIONS

AHRS	Attitude and Heading Reference System
AMST	Advanced Medium STOL Transport
ASPR	Armed Services Procurement Regulation
COD	Correction of Deficiencies
CODSIA	Council of Defense and Space Industry Associations
DoD	Department of Defense
DDR&E	Director of Defense Research and Engineering
ECP	Engineering Change Proposal
EPG	European Participating Governments
ETI	Elapsed-Time Indicator
FLU	First-Line Unit
FMS	Foreign Military Sales
GMTBF	Guaranteed Mean Time Between Failures
HUD	Head-Up Display
INS	Inertial Navigation System
LCC	Life-Cycle Cost
LSC	Logistics Support Cost
LRU	Lowest Replaceable Units
MTBF	Mean Time Between Failures
OASD (I&L)	Office, Assistant Secretary of Defense (Installations and Logistics)
O&M	Operation and Maintenance
OR	Operational Readiness
RIW	Reliability Improvement Warranty
STOL	Short Take-Off and Landing
TACAN	Tactical Navigation (Set)
TAT	Turn-Around Time
TLSC	Target Logistics Support Cost
TOA	Total Obligational Authority
TOH	Total Operating Hours
UCC	Uniform Commercial Code
USAF	United State Air Force

I. INTRODUCTION

THE PROBLEM

In the absence of an offsetting decline in acquisition costs, the lifetime expenditure required by typical modern weapons--their life-cycle cost--has been rapidly increasing. The availability of crucial systems is poor: FY 1976 operational readiness (OR) rates for Navy fighters--46.5 percent for the F-4 and 32.9 percent for the F-14--are examples.[1] Operation and maintenance (O&M) costs are rising: for example, in FY 1964, Air Force O&M costs accounted for $4.27 billion out of a total obligational authority (TOA) of approximately $20 billion (21 percent); for FY 1978, the Air Force requested $9.8 billion for O&M out of a requested TOA of $35.3 billion (28 percent).[2]

Important factors contributing to poor availability and high O&M (or support) costs are inadequate system reliability and maintainability. Reliability refers to the probability that an item will perform a required function under specified conditions, without failure, for a specified period of time.[3] Maintainability refers to "the ease with which an item may be tested, repaired, and installed."[4]

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[1] Information submitted for the record by the Navy to the Senate Armed Services Committee, reprinted in *Aerospace Daily*, 28 April 1977. The full systems capable readiness rates were 30.2 percent for the F-4 and 27.8 percent for the F-14. Unweighted averages for the 27 aircraft systems measured were 57.0 percent (operational readiness) and 46.8 percent (full systems capable).

[2] Maj. Gen. R. F. Trimble, then Director of Procurement Policy, Office of Deputy Chief of Staff, Systems and Logistics, United States Air Force, in *Proceedings of Aviation Supply Office Failure Free Warranty Seminar, Held in Philadelphia, Pennsylvania, on December 12-13, 1973*, p. 121; Lt. Gen. Alton D. Slay, Deputy Chief of Staff, Research and Development, United States Air Force, in House Committee on Armed Services, *FY 1978 DoD Appropriation Authorization, Hearings*, 95th Cong., 1st Sess., Part Two, p. 342.

[3] AFM 11-1, Vol. 2.

[4] Joseph A. Bizup and Randall R. Moore, *Technique for Selecting and Analyzing Reliability Improvement Warranties*, Naval Air Systems Command, R-7505, June 1975 (rev. June 1976), p. 5. See also AFM 11-1, Vol. 2.

It is widely believed that manufacturers pay inadequate attention to their products' reliability and maintainability because most weapon system contracts fail to burden the contractor with a major portion of the life-cycle costs. Figure 1 illustrates the typical contractual distribution of burdens and risks. The "cost to produce" curve represents the usual costs incurred up until delivery of the product from the contractor to the using command (often termed "acquisition cost"). From that point on, the buyer exclusively and explicitly bears the costs of supporting the product. Profit is roughly equal to contract price less the "cost to produce," so the incentive in this situation is to meet only the minimum acceptable reliability level (point r) where profit is greatest.[1] Moreover, to the extent that the producer has no competition in providing replenishment spares and support equipment, he has even less incentive to achieve more than minimum reliability.

All other things equal, improved system reliability (like improved maintainability) reduces support costs (see Fig. 2). If a contractor were sensitive to both production and support costs (the sum being termed "total contractor cost"),[2] then *in theory* reliability will improve (from r to r'). (Note that in Fig. 2 the contractor would seek any reliability improvement intended to reduce his total costs only when the pre-warranty reliability level falls to the left of r'.) The cost to the *buyer* of this improvement, on the surface, will be the amount of any negotiated upward adjustment of the contract price (the difference between p^* and p) necessitated by the redistribution of burden and risk.

Although the U-shaped total contractor cost curve is commonly accepted as a simplified but valid description of the reliability incentive inherent in a fixed price warranty, it is not the only

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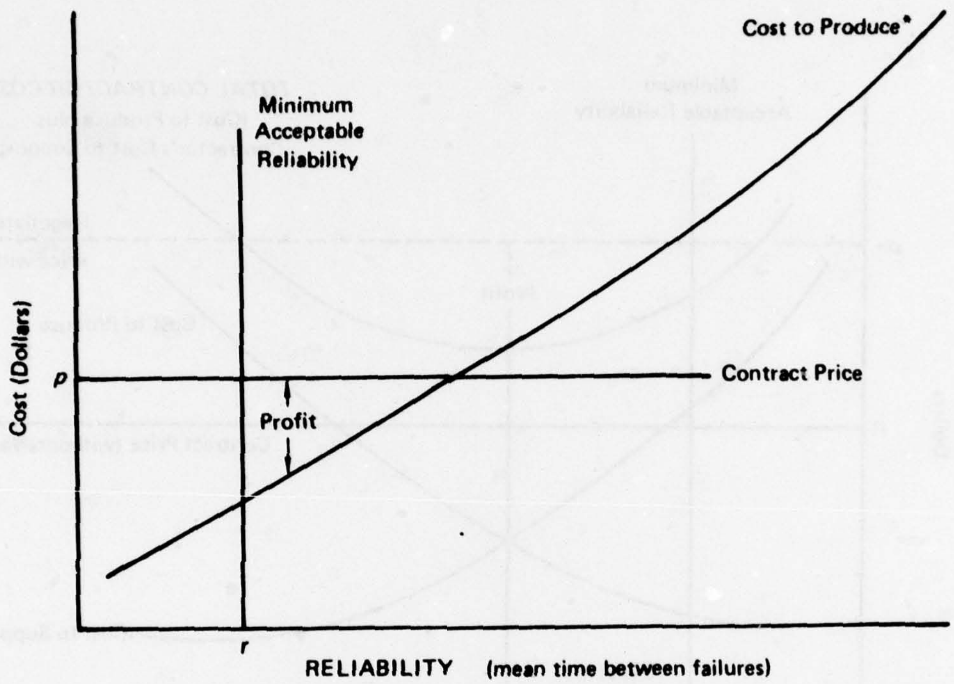
[1] Two caveats must be mentioned. First, this of course describes an environment of fixed price contracts. Second, it is an intentional oversimplification of the incentive mechanism. The role of profit maximization in the defense sector is neither explicit nor unequivocal owing to difficulties in defining profit and the special importance of sales and other factors in determining "maximization behavior."

[2] The model in Fig. 2 tells nothing about the way an improvement in reliability affects the *buyer's* total costs (contract price plus buyer's O&M costs).



*Curve is a frequently used representative illustration of the positive correlation between reliability and cost, *ceteris paribus*.

Fig. 1 — Representative illustration of cost vs. reliability

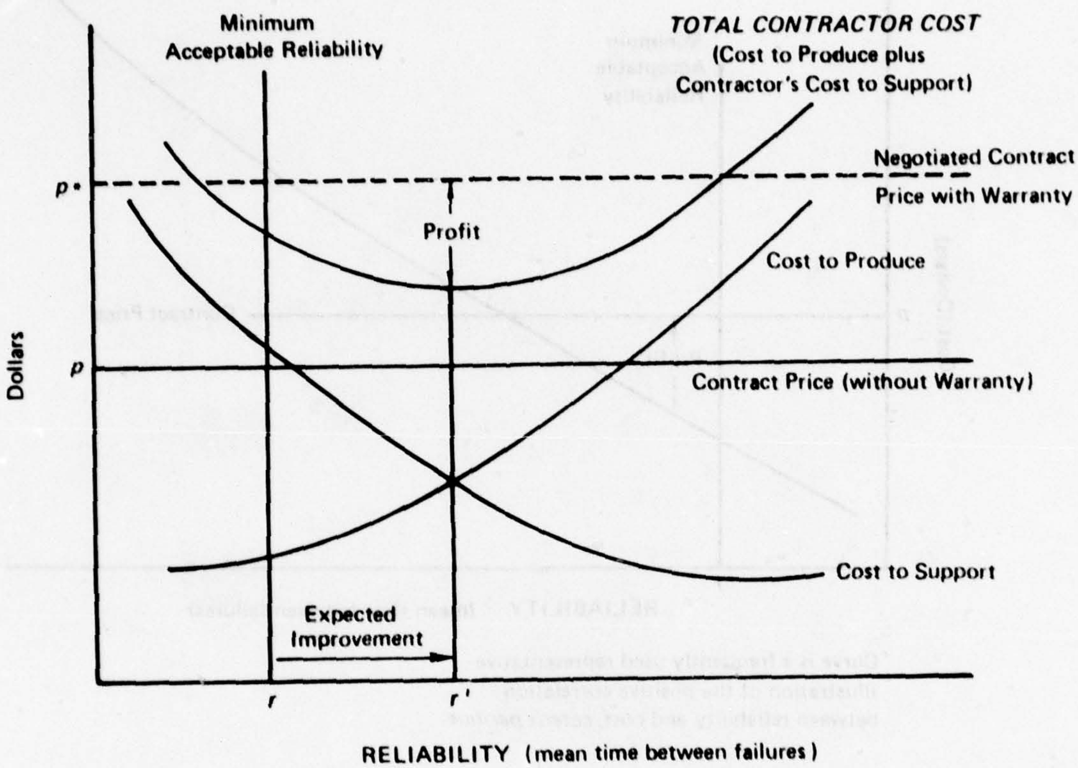


Fig. 2 — Theoretical operation of reliability improvement incentive

possible product resulting from the summation of the cost-to-produce and the cost-to-support curves. Depending on the slopes of these two curves, it is also possible to produce a total cost curve that is horizontal, or continually rising, or continually declining over the relevant regions. Assuming a fixed contract price, in the first case a profit would be the same at all levels of reliability; in the second case maximum profit would be obtained at the minimum acceptable reliability; in the third case maximum profit is obtained at maximum attainable reliability. Unless the slopes of these two curves are known, a profit-maximizing contractor's behavioral response to a warranty would be difficult to predict. Identification of the proper total cost curve (and therefore probable contractor response) is more difficult when the item to be procured is still in the concept or design stage, because the reliability and cost-to-produce or cost-to-support relationships are not known. Current efforts to encourage reliability improvement, which this report examines, proceed from the model in Fig. 2.

RESPONSES TO THE PROBLEM

Efforts to provide contractors incentives to design in reliability and low-cost support features generally have not been successful. Past attempts have included (1) inclusion of target mean time between failures (MTBF) in performance specifications along with target unit production cost goals, and (2) solicitation of life-cycle cost (LCC) estimates from competing contractors to incorporate them into the source selection decision process. The latter technique is still in wide use; over a dozen current Air Force programs have featured it, including the F-16 and the Advanced Medium STOL Transport (AMST). The weakness of both methods is the absence of enforcement features: After the contract award to a sole source, no mechanism ensures that the target or submitted estimates will be in fact obtained. Accordingly, several of the programs using LCC estimates in source selection decisions also feature one of several new contractual incentive provisions.

In general, traditional contractual incentives, such as award fees based on achieving acquisition cost targets, have not had an

appreciable effect on contractor motivation.[1] Available evidence suggests that subsequent events usually influence these types of defense incentive contracts rather than being constrained or influenced by them, and lead to accommodating modifications of terms.[2] However, the Department of Defense has recently begun experimenting with the following special contractual terms that seek to address contractor motivation specifically to reduce support costs and improve product reliability:

1. Target Logistics Support Cost Commitment/Correction of Deficiencies (TLSC/COD)
2. Reliability Improvement Warranty (RIW)
3. RIW with a Guaranteed Mean Time Between Failures (RIW with GMTBF).

Target Logistics Support Cost Commitment

TLSC/COD establishes logistics support cost (LSC) targets in the contract for the whole system, for a variety of subsystems, or for first-line units (FLUs). After a specified operating period (usually measured in operating time), the LSC for each unit is measured and compared with the target LSCs. If the measured LSC does not exceed the target by a stipulated amount (e.g., 25 percent in the General Dynamics F-16 contract), the contractor receives an additional cash

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[1] Russell R. Shorey, Director of Acquisition and Support Planning, Office of the Assistant Secretary of Defense (Installations and Logistics), "Factors in Balancing Government and Contractors Risk with Warranties," in *Proceedings, 1976 Annual Reliability and Maintainability Symposium*, p. 366.

[2] This finding, by Arthur J. Alexander of The Rand Corporation, is reported in an appendix titled "Experience of the Department of Defense with Incentive Contracting," in Leland L. Johnson et al., *Alternative Institutional Arrangements for Developing and Commercializing Breeder Reactor Technology*, The Rand Corporation, R-2069-NSF, November 1976. This phenomenon has also been observed in the setting of light water reactor construction. See Robert Perry et al., *Development and Commercialization of the Light Water Reactor, 1946-1976*, The Rand Corporation, R-2180-NSF, June 1977, pp. 20-25.

award.[1] For certain FLUs, the contract may include a clause obligating the contractor to take corrective action (test, redesign, retest, retrofit) to bring the LSC within the prescribed margin for a predetermined price.[2] The government has the option to invoke this correction of deficiencies (COD) clause when the measured LSC for a unit exceeds the target by more than the stipulated "cushion." Of the three approaches, the TLSC commitment is both the least ambitious, in terms of its novelty, and the least widely used.[3] This report focuses on the RIW concept and the variation combining the warranty with a guaranteed reliability level.

Reliability Improvement Warranty and MTBF Guarantee

The most frequently used technique for "buying reliability" is a warranty clause--in current DoD parlance, a *reliability improvement warranty* (RIW). In some respects, the RIW is identical to the familiar warranty accompanying most consumer products. Under an RIW, the contractor normally assumes responsibility on a firm fixed price basis for repairing or replacing (as he sees fit) warranted units that fail during the warranty period. The difference between the fixed warranty contract price and the expenses incurred in performing under the warranty is profit, so that contractor has an incentive to minimize repair/replacement costs (and thus to improve reliability).

An RIW variation combines the warranty with a guarantee of a certain reliability level (expressed in MTBF). If the computed MTBF for a given measurement period falls below the guaranteed value for the period, the contractor must provide the following:

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[1] This is the so-called "award fee" version. One USAF program, the AN/ARC-164 UHF Radio, features an "incentive fee" provision under which the contractor can earn up to $10.4 million but can also lose up to $10.4 million.

[2] The ARN-118 TACAN program is the only one with a TLSC commitment that does not include a COD clause.

[3] The Air Force is using the technique on four programs: (1) F-16 (three FLUs)--(a) Radar/E-O Display, (b) Digital Scan Computer, (c) Fire Control Computer; (2) A-10 (called "Target Logistics Effect"); (3) AN/ARN-101 Tactical LORAN; and (4) AN/ARC-164 UHF Radio.

1. Engineering analysis identifying the causes of noncompliance.
2. No-cost (to the government) engineering change proposals (ECPs).
3. Modification of all existing units in accordance with the approved changes (at contractor expense).
4. Consignment spares for government use until it is shown that the guaranteed MTBF is being achieved. (These become the government's property at no extra charge at the end of the warranty period if the guarantee is not met.)[1]

The key difference between the RIW alone and the RIW with the guarantee, of course, is the obligation under the guarantee to upgrade all units (including those already in the field) in the event that reliability measurements fall below the guarantee level.

The RIW is the principal contractual approach under investigation by the Department of Defense for improving the reliability and reducing the life-cycle cost of modern weapon systems. The current DoD-wide *experimentation* is the result of an August 1974 memorandum from OASD (I&L) and DDR&E.[2] Roughly 30 items have been procured under warranty by the services in the last 13 years. The Air Force alone is currently procuring 16 items under RIW, more than half of which are F-16 subsystems and components; responsibility for these trial applications resides with the Directorate of Procurement Policy, Office of the Deputy Chief of Staff (Systems and Logistics). Depending on the number of contract options exercised, the Air Force warranty expenditure will likely exceed $65 million.

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[1] The consignment spares provision is not included in all warranty contracts with a guarantee. See Richard Kowalski and Roy White, "Reliability Improvement Warranty and the Army Lightweight Doppler Navigation System (LDNS)," in *Proceedings, 1977 Annual Reliability and Maintainability Symposium*, Washington, D.C., 1977, pp. 240-241; Ronald A. Mlinarchik, "RIW Experience at ECOM," ibid., p. 258.

[2] Memorandum to the Assistant Secretaries of the Military Services from the Assistant Secretary of Defense (Installation and Logistics) and the Director of Defense Research and Engineering on "Trial Use of Reliability Improvement Warranties in the Acquisition Process of Electronic Systems/Equipment," 13 August 1974, and attached "Reliability Improvement Warranty Guidelines."

OBJECTIVES OF THE STUDY

It is widely believed that RIWs offer an effective way to improve military equipment reliability levels. However, neither their effectiveness nor their appropriateness are well understood. Therefore, this study had three purposes: (1) to survey and describe, across programs, the substantive terms of existing RIW contracts (Sec. II); (2) to reassess the soundness of the RIW concept and experiment by considering the commercial experience used as a model; and (3) to summarize, where possible, the outcomes of completed DoD warranty contracts (Sec. III).

The ambiguity of the practical meaning of risk redistribution described above can inhibit assessment of the RIW approach. On the one hand, an RIW may be viewed simply as an insurance policy providing enforceable contractual damage claims as a hedge against poor reliability. On the other hand, it may be viewed as a device to motivate contractor design and manufacturing behavior.[1] Although both views recognize the contractual redistribution of risks and burdens, actual reliability improvement is important only to the second one; it is largely irrelevant to the first. Although no consensus has developed on the priority of RIW objectives, the RIW is apparently intended primarily to motivate contractors and secondarily to be an insurance policy. Reflecting not only a concern for life cycle costs but also for operational readiness, *reliability improvement*[2] is the prime goal. This is supported by official statements about the RIW (as well as its name):

> The objective of an RIW is to motivate and provide an incentive to contractors to design and produce equipment which will have a low failure rate as well as low repair costs after failure due to field/operational

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[1] An additional by-product is that the contractor must reveal his estimation of the capitalized life cycle costs during the warranty period.

[2] There is disagreement even as to what this term means. Some argue that it compares reliability achieved under a warranty with the reliability hypothetically achievable without a warranty; others argue that it refers to reliability growth over the warranty coverage period. The term as it is most widely used seems to incorporate both variations.

> use. Furthermore, this technique attempts, through the use of contractual agreements (where the period of performance extends over several years) to provide an incentive for contractors to improve the reliability of their equipment and to reduce repair costs during the period of warranty coverage in order to maximize their profits.[1]

Our discussion of the RIW will be shaped by this hierarchy of goals. The chief concern of the analysis in Sec. III will be whether RIWs in the past actually resulted in more reliable products and if they can be expected to do so in the future.

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[1] Headquarters, United States Air Force, DCS/Systems and Logistics, Directorate of Procurement Policy, "Interim Guidelines: Reliability Improvement Warranty," July 1974, pp. 1-2. These guidelines have not been updated.

II. RELIABILITY IMPROVEMENT WARRANTY CHARACTERISTICS

This section discusses the substance of the reliability improvement warranty; it is based on a survey of 18 Air Force warranty procurements:

- The 16 current RIW procurements.[1]
- The current Air Force administered purchase under warranty for the Foreign Military Sales (FMS) program (of an item the Air Force is also purchasing under warranty for its own use).
- The F-111 Displacement Gyroscope Platform warranty.

Although the warranty period in the F-111 gyro contract has ended, it is included because of the attention paid to it by the procurement community. This sample is listed in Table 1. Other than for one early (F-111 gyro) and one small (hydraulic pump) contract involving mechanical equipment, application of the RIW concept has concentrated on electronics equipment (see Table 2). The volume of the buys varies considerably in units purchased and dollars expended. But in the aggregate, the RIW program is significant; assuming all the options are exercised, the total hardware cost of the current programs (excluding warranty price) will be around $500 million.

STATEMENT OF CONTRACTOR WARRANTY

At the core of any warranty is the basic promise made by the warrantor. The wording of this promise is very nearly standardized among Air Force RIW programs:

> Notwithstanding Government inspection and acceptance of supplies and services furnished under this contract..., the contractor warrants that all [items] furnished under this contract will be free from defects in design,

---

[1] The nine F-16 components will generally be treated as a single program, however.

Table 1

USAF APPLICATIONS OF RELIABILITY IMPROVEMENT WARRANTIES

Item	Initial Contract Date	Warrantor	Manufacturer	MTBF Guarantee?
(1) Displacement gyro platform F-111	1969	Lear Siegler Instruments Grand Rapids, Michigan	Lear Siegler Instruments Grand Rapids, Michigan	No
(2) AVU-8C/A airspeed indicator F-16 test aircraft	1975	Bendix Davenport, Iowa	Bendix Davenport, Iowa	No
(3) Hydraulic pump C-130	1975	Abex (IC Industries) Oxnard, California	Abex (IC Industries) Oxnard, California	No
(4) Klystron electron tube	1975	Varian Associates Palo Alto, California	Varian Associates Palo Alto, California	No
(5) Attitude and heading reference system (AHRS) C-141	1975	Lear Siegler Instruments Grand Rapids, Michigan	Lear Siegler Instruments Grand Rapids, Michigan	Yes
(6) Inertial navigation system (INS) C-141/KC-135	1975	Delco Electronics (General Motors) Goleta, California	Delco Electronics (General Motors) Goleta, California	Yes
(7) ARN-118(V) TACAN set USAF buy	1975	Collins Radio (Rockwell International) Cedar Rapids, Iowa	Collins Radio (Rockwell International) Cedar Rapids, Iowa	Yes
(8) ARN-118(V) TACAN set FMS buy	1976	Collins Radio (Rockwell International) Cedar Rapids, Iowa	Collins Radio (Rockwell International) Cedar Rapids, Iowa	No
(9) Low-cost Omega navigation set C-130	1976	Dynell Electronics Melville, New York	Dynell Electronics Melville, New York	Yes
(10) Radar transmitter F-16	1977	General Dynamics Fort Worth, Texas	Westinghouse Electric Baltimore, Maryland	Yes

Table 1 (continued)

Item	Initial Contract Date	Warrantor	Manufacturer	Guarantee?
(11) Head-up display (HUD) electronics F-16	1977	General Dynamics Fort Worth, Texas	EA Industries (Marconi-Elliott Bros., Ltd., Rochester, Kent, England) Chamblee, Georgia	Yes
(12) Flight Control Computer F-16	1977	General Dynamics Fort Worth, Texas	Lear Siegler Instruments Santa Monica, California	No
(13) Radar low power RF F-16	1977	General Dynamics Fort Worth, Texas	Westinghouse Electric Baltimore, Maryland	No
(14) Radar digital signal processor F-16	1977	General Dynamics Fort Worth, Texas	Westinghouse Electric Baltimore, Maryland	No
(15) Radar computer F-16	1977	General Dynamics Fort Worth, Texas	Westinghouse Electric Baltimore, Maryland	No
(16) Head-up display (HUD) F-16	1977	General Dynamics Fort Worth, Texas	EA Industries (Marconi-Elliott Bros., Ltd., Rochester, Kent, England) Chamblee, Georgia	No
(17) Navigation unit F-16	1977	General Dynamics Fort Worth, Texas	Singer (Kearfott Division) Little Falls, New Jersey	No
(18) Radar antenna F-16	1977	General Dynamics Fort Worth, Texas	Westinghouse Electric Baltimore, Maryland	No

Table 2

USAF RIW CONTRACTS: TYPE OF EQUIPMENT, NUMBER OF UNITS, UNIT PRICE

Contract	Type of Equipment	No. Units Under Warranty	Unit Price (not including warranty)
F-111 gyro	Electro/mechanical	128	$ 6,040
Airspeed indicator	Electronics	24	1,986[a]
Hydraulic pump	Mechanical	28	1,800
Klystron electron tube	Electronics	264	890
AHRS	Electronics	275[b]	12,790[c]
INS	Electronics	1,073[d]	54,891
TACAN (USAF)	Electronics	8,586[e]	9,358
TACAN (FMS)	Electronics	750	9,448
OMEGA Navigation set	Electronics	1,464[f]	10,430
F-16 components	Electronics	442[g]	h

[a]Warranty was not separately priced. Estimated portion of $2,211 unit price attributable to warranty coverage is $225.

[b]Basic buy nine units, option for 266 more.

[c]Median price taking account of option variations.

[d]Basic buy two units, without warranty. Warranty coverage begins with exercise of first option. Options total 1,071 units.

[e]Basic buy 1,000 units, option for 7,586 more.

[f]Basic buy 264 units, option for 1,200 more.

[g]Warranty covers equipment in 250 USAF aircraft and 192 European aircraft.

[h]The prices of individual components are unavailable; however, the total price of all components is $406 million.

> material and workmanship and shall operate in its intended environment in accordance with (accompanying exhibits or governing specifications for a stated period).

Some contracts mention only defects in material and workmanship, omitting design defects. This inconsistency does not appear to be significant because the scope of the contractor's obligation is set by the contractual definition of product failure.

DEFINITION OF FAILURE

The contractor's primary obligation under an RIW is to repair or replace, at its own option (and for a fixed price), items furnished under the contract that fail to meet the warranty. The definition of failure is therefore a crucial determinant of the contractor's required performance. The broadest definition of "failure" includes all units removed from operation because of a determination that they do not perform in accordance with the warranty. Four Air Force programs use this approach (INS, AHRS, Hydraulic Pump, F-16 components). Inevitably, some units removed by the government and returned to the contractor will be found to be free from any defect. These are termed "unverified failures."

An alternative definition of failure includes only those units verified by the contractor to have failed (or to be in nonconformance). If this definition is used, there is usually a provision for adjustment of the warranty price (or for payment on a repair-by-repair basis) if the number of "unverified" returns exceeds a specified percentage of total returns in a reporting period (e.g., 30 percent in the TACAN (USAF) program).

The warranty does not obligate the contractor to fix or replace *all* failed units. Failures due to certain events are excluded from coverage:

1. Crash
2. Explosion
3. Fire
4. Submersion

not induced by the warranted item

not on the contractor's premises

5. Act of God (flood, hurricane, etc.)
6. Improper installation or maintenance by the government
7. Tampering or willful mistreatment by the government[1]
8. Combat action

The government usually negotiates a separate contract with the contractor to cover the repair or replacement of units excluded from warranty coverage because of one of the above.

WARRANTY PERIOD

The warranty period is the time during which the warranty is in effect. This can be measured either in calendar time or equipment operating hours. Some Air Force contracts use only calendar time; others provide that the warranty will continue in effect for a certain number of calender years *or* a certain number of equipment hours *whichever occurs first* (see Table 3). The table reveals a number of alternative constructions:

- *Calendar time* can be measured:
  from delivery or acceptance of the first unit,
  from delivery or acceptance of each unit (implying staggered, unit-by-unit periods of coverage),
  in terms of the warranted item or the aircraft in which it is to be installed,
  for a specified period or until a specified date.
- *Equipment hours* can be measured:
  in terms of the warranted item or the aircraft in which it is to be installed;
  in *flying* hours or *operating* hours;
  on *each* unit (implying staggered, unit-by-unit periods of coverage) (e.g., Klystron electron tube); or *cumulatively* on *all* units (e.g., F-16 components); or by a per unit average (e.g., Hydraulic Pump).

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[1]Failure from *accidental* mistreatment is excluded in at least two RIW programs, the Air Force's ARN-118(V) TACAN and the Army's ARN-123(V) Radio Receiver.

Table 3

WARRANTY PERIODS OF AIR FORCE RIW CONTRACTS
(Basic quantities and for basic coverage only)

Contract	Coverage
	Calendar Time Only
(1975)[a] TACAN	5 yrs. from date of delivery of *first* unit
(1975) INS	4 yrs. from date of acceptance of *first* unit
(1975) AHRS	5 yrs. from date of acceptance of *first* unit
(1975) Airspeed indicator	5 yrs. from date of acceptance of *each* unit
(1975) Navigation set	5 yrs. from date of acceptance of *first* unit
	Calendar Time or Equipment Hours (whichever occurs first)
(1969) F-111	5 yrs. from date of delivery of *each* unit[b] 3,000 *operating* hours on *each* unit
(1975) Klystron electron tube	4 yrs. from date of delivery of *each* unit, or 1,000 *operating* hours on *each* unit
(1975) Hydraulic pump	7 yrs. from date of delivery of *first* unit, or 5,000 *flying* hours on *all* units *(averaged)*
(1977) F-16 components	4 yrs. from date of delivery of first production *aircraft*, or 300,000 *accumulated flying* hours

[a]Contract date.

[b]A single warranty cutoff date (26 November 1976) was subsequently negotiated.

Presumably, within a single procurement, coverage of some units will be delimited by calendar time and coverage of others will be delimited by operating or flying hours.

In general, the period of warranty coverage should be long enough to encourage the contractor's investment in product improvement so he can recover that investment (with profit).[1] The choice of definition in calendar time or in equipment hours involves a tradeoff between administrative efficiency and accurate reflection of the fact that the "commodity" being purchased is utility and not time. However, the services must plan for transitioning from warranty coverage to another logistics support concept (perhaps organic maintenance), making this choice especially important. That is, if a surge foreshortens the calendar length of warranty coverage, available time for transition planning is also reduced. In practice, calendar year coverage in the alternative form is intended to motivate shelf-life improvement as much as reliability improvement.

The choice between operating and flying hours is also usually one of convenience. The better measure, *operating hours*, is more difficult to monitor accurately, and reliable factors for converting flying hours to equipment total operating hours are still being developed. The latest set of warranty contracts (F-16 components) uses *aggregate* flight hours of all the aircraft equipped with warranted items. A cumulative operating or flight hours measure is sometimes advocated over a specific unit limitation because "fleet operating conditions are such that the use of individual units cannot be easily controlled. Some will be used intensively and some, for one reason or another, not at all."[2]

Although warranty coverage length should depend on each procurement's circumstances, the current wide variation is not the result of planned experiment. This will make it difficult, if not impossible, to draw any prescriptive guidance for future applications from the trial warranty outcomes.

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[1] This reflects the prevailing view.

[2] Captain G. R. Henry, "FFW Contractual Considerations," in *Proceedings of Aviation Supply Office Failure Free Warranty Seminar*, p. 84.

TURN-AROUND TIME

Each RIW clause specifies the time of repair or replacement. This turn-around time (TAT) usually represents the period the government will be without the unit. However, under some RIW contracts, the contractor is required to maintain a bonded storeroom of units from which he must ship a replacement unit upon notification of a failure. In this situation, the TAT represents the time for repair/replacement and return to storage. Table 4 presents the TAT provisions of the Air Force RIW contracts.

For three of these programs (F-111 Gyro, Airspeed Indicator, and Klystron electron tube), there are *no* penalties for failure to meet the TAT required. Penalties in the other programs take one of these forms:

1. Extension of the warranty period,
2. A liquidated damage payment, or
3. Consignment spares provided within a specified period.

The Hydraulic Pump contract provides for a five day warranty extension for each TAT day overrun. The Air Force TACAN contract obligates the contractor to pay damages at the end of each six-month reporting period in the amount of:

$$d = \$25 \times (TAT_m - TAT_r) \times R,$$

where d = liquidated damages due each period,

TAT_m = measured average TAT during period (days),

TAT_r = required TAT (15 days),

R = number of returns during the period

The most common penalty, included in all programs featuring a guarantee except the TACAN, requires consignment spares (to compensate for the "extra" time the government was without the item).

Table 4

AIR FORCE RIW CONTRACTS: TARGETED TURN-AROUND TIMES
(Asterisks indicate goal, not guarantee)

Contract	TAT (days)	Measurement (from receipt to--)
*F-111 gyro	45 (avg.)	Shipment; avg. over life of warranty
*Airspeed indicators	30	Shipment
INS[a]	4-7[b] (avg.)	Storage; avg. over 3-month periods
AHRS[a]	22[c]	Storage
*Klystron electron tube	120	(Unknown)
*Hydraulic pump	10	(Unknown)
TACAN (USAF)	15 (avg.)	Return; avg. over 6-month periods
TACAN (FMS)	20	Shipment
OMEGA navigation set[a]	15 (avg.)	Shipment; avg. over 6-month periods
F-16 components	22 (avg.)	Storage; avg. over 6-month periods

[a]Contract includes a shipment from bonded storeroom requirement. Required shipment times range from one to four days.

[b]Four days if repaired at a Military Airlift Command base; seven days if repaired at contractor's facility.

[c]Termed "Shop Flow Time (SFT)."

The following formula determines the number of spares to be consigned:[1]

$$n = K(TAT_m - TAT_r) - L_p,$$

where n = number of consignment spares required (rounded to next highest integer),

T_m = measured average TAT (in days),

T_r = required TAT,

L_p = consignment spares currently in government's possession (including amount of spares represented by any liquidated damage payments made according to provisions listed in Table 6, page 24),

$$K = \frac{\text{avg. no. operating units x avg. operating hrs. per day}}{\text{guaranteed MTBF}}.$$

The required times for provision of these spares and the penalties for lateness are listed in Table 5.

Failure to meet required TATs is normally excluded if the failure is beyond the contractor's control and without his fault or negligence. For example, acceptable excuses in the TACAN program include:

- Acts of God
- Acts of a public enemy
- Acts of the government
- Fires
- Floods
- Epidemics
- Strikes
- Freight embargoes
- Unusually severe weather.

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[1] Variations include: <u>F-16 components</u>: K assumed to be equal to 1. <u>AHRS, C-141</u>: following expression is added to basic formula:

$$0.06(I)\left\{\frac{MTBF_G}{MTBF_M} - 1\right\},$$

where 0.06 = max. spares quantity (17) ÷ total installed items (275),

I = current number of installed units,

$MTBF_G$ = guaranteed MTBF,

$MTBF_M$ = latest measured MTBF (cannot be > $MTBF_G$).

Table 5

AIR FORCE RIW CONTRACTS: REQUIRED TIME FOR PROVISION OF TAT-RELATED CONSIGNMENT SPARES AND ASSOCIATED PENALTIES

Contract	If Still in Production	If Out of Production	Penalty
OMEGA Navigation set	90 days	270 days	$50 each extra day, up to 50% of unit price
INS	30 days	90 days	3-1/3% of unit price each extra day, up to 50% of unit price
AHRS	30 days	90 days	None
F-16 components	45 days	120 days	50% of unit price for any late delivery

Like the length of warranty coverage, the penalty, if any, for failure to meet TAT requirements is neither uniform nor variable according to a conscious plan. Even within types--e.g., provision of *consignment spares*--penalty provisions vary. There are as many different constructions being "tested" as there are test cases.

ADDITIONAL PRICE ADJUSTMENT PROVISIONS

Operating Hours

When the warranty period is defined strictly in calendar time, how much the government uses its product during the period greatly affects the contractor's performance cost. For initial pricing purposes, programs featuring warranty period definitions of this type include a provision for adjusting the warranty price to *actual* usage.

Of the five programs with calendar year warranty periods, four include operating hours price adjustment clauses. The warranty in the fifth program (Airspeed indicators) was not separately priced. All four allow both upward and downward adjustments, although all limit the allowable downward revision. The F-16 components warranty, which has a "calendar time or equipment hours" warranty period, provides for limited downward adjustment if the four-year warranty period expires and

accumulated flying hours at the expiration date fall below a specified level. Table 6 summarizes provisions for price adjustments based on operating hours.

Lost and Damaged Units

Some warranties specifically adjust for units lost, destroyed, or damaged beyond repair in ways that exclude them from coverage. The rationale for such adjustments is that the government should not have to pay for warranty protection for unusable units and that the contractor should not receive such payments because he will not have to expend any resources to support those units. The programs with operating hour price adjustment provisions generally address this phenomenon. However, the TACAN (USAF) program includes a reimbursement formula for the price associated with the "unused" portion of the warranty arising out of lost units or excluded failures. Loss of the entire TACAN set, for example, reduces the warranty price by $1 for each remaining day of the warranty period. The F-111 Gyro and Airspeed Indicators programs provide for adjustment negotiations at the time of final contract close-out. Finally, the Hydraulic Pump and F-16 components programs credit the government with "unused" warranty coverage when it repairs or replaces units that are either lost or suffer excluded failures.

REPAIR OF EXCLUDED FAILURES AND REPLACEMENT OF LOST UNITS

All Air Force RIW contracts allow the government to direct the contractor to repair or replace units that suffer excluded failure or are lost. Most specify that the transactions are to include price negotiations and about half permit transfer of warranty coverage to the new or repaired unit (see Table 7). The TAT provisions for warranted items usually do not apply to this type of repair and replacement.

MTBF GUARANTEES

The Air Force is buying six items that, in addition to being warranted to work, are guaranteed to achieve a specified level of reliability (expressed in terms of mean time between failures):

Table 6

AIR FORCE RIW CONTRACTS: PROVISIONS FOR PRICE ADJUSTMENTS BASED ON OPERATING HOURS

Contract	Expected Usage Rate (operating hours per month)	Time of Adjustment	Standard for Adjustment
TACAN (USAF)	68	Yearly	For a deviation (between expected and actual usage rate) > ± 5%, contract price altered ± $0.50 x avg. deviation x avg. number of installed sets during period.
AHRS	160	End of warranty	Ratio of expected to actual usage rates.
OMEGA navigation set	50	Yearly	For a deviation > ± 5%, contract price altered ± *$0.44* x avg. *deviation* x avg. number of installed sets during period.
INS	160 (C-141) 55 (KC-135)	Yearly	Ratio of expected to actual usage rates (downward price adjustment cannot be greater than 50%).
F-16 components	300,000[a]	End of warranty[b]	Warranty price on each FLU reduced by 0.000172% per hour for each hour under 250,000, not to exceed an adjustment of 43%.[c]

[a] *Accumulated flying* hours.

[b] Assuming period ends by virtue of calendar year provision (four years).

[c] That is, the original price is adjusted by multiplying it by: $57 + (.172 \times 10^{-5})\ (250{,}000 - AFH)$, where AFH = *actual* accumulated flying hours.

1. OMEGA Navigation Set,
2. Attitude and Heading Reference System (AHRS) for the C-141,
3. Inertial Navigation System (INS) for the C-141 and the KC-135,
4. ARN-118(V) TACAN Set (the Air Force buy),
5. F-16 Radar Transmitter,
6. F-16 Head-up Display (HUD) electronics.

The Air Force's commitment to the guarantee feature is apparently strong because all the major warranty programs include it. If the guaranteed levels are not met, the guarantee obligates the contractor to identify the causes of the deficiency, propose and carry out modifications (on all units) to correct it, and provide consignment (or "pipeline") spares in the interim. There are several variable characteristics of the MTBF guarantee, including (1) equipment level of guarantee, (2) single value versus incremental goals, (3) frequency of calculation, (4) method of calculation, and (5) early termination of obligation provisions.

Table 7

AIR FORCE RIW CONTRACTS: REPAIR OF EXCLUDED FAILURES AND REPLACEMENT OF LOST UNITS

	Price		Warranty Applicability		
Contract	Set	Negotiated	Coverage	No Coverage	Unclear
F-111 gyro		X	X		
Airspeed indicator		X	X		
INS		X	X		
AHRS		X		X	
Klystron electron tube		X			X
Hydraulic pump		X[a]		X	
ARN-118(V) TACAN (USAF)		X			X
OMEGA navigation set	X		X		
F-16 components		X[a]		X	

[a]Price includes a credit for remaining warranty coverage on the damaged or lost unit.

Equipment Level of Guarantee

Should the design of a guarantee concern the reliability of the whole product (or first-line unit), the reliability of subunits of the product (lowest replaceable units or shop-replaceable units--LRUs and SRUs), or the reliability of both the whole product and individual subunits? The F-16 components are the only items guaranteed exclusively at the FLU level. The TACAN contract specifies TACAN MTBF levels, which the contractor then must apportion among four subunits. Measurements are made subunit by subunit. Similarly, the INS and OMEGA Navigation Unit contracts specify apportioned subunit MTBF values. The AHRS guarantee is the only hybrid example: It requires that "in addition to achieving the guaranteed system MTBF, the contractor must achieve the MTBF guarantee for each LRU and SRU."

Single Value Versus Incremental Goals

A second design issue is whether to require the contractor to achieve a single, stated MTBF goal or a succession of goals over the period of the warranty. Examples of the first approach include the INS and AHRS guarantees. The other guarantee programs feature a succession of incremental goals:

1. The TACAN and F-16 components contracts require a higher reliability level each year;
2. The OMEGA Navigation Set contract requires a higher reliability level every six months for the first three years (and additional improvement over the last two years).

The growth rates in the two sets of contracts are strikingly dissimilar. For example, the improvement reflected by a comparison of the final goal with the initial goal is 60 percent for the TACAN, 54 percent for the F-16 HUD electronics, 34 percent for the F-16 radar transmitter, and 444 percent for the OMEGA Navigation Set.[1]

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[1]The OMEGA contract has MTBF guarantees at the LRU level only. The figure used for the system MTBF is the reciprocal of the sum of the reciprocals of the LRU MTBFs. Also, the TACAN and HUD electronics improvement is to be achieved over three years, five years for the OMEGA. However, the OMEGA contractor has guaranteed a 423 percent MTBF improvement by the end of the third year.

Frequency and Method of Calculation

The preceding discussion implies comparison of measured MTBFs and guaranteed MTBFs at varying frequencies, but frequency of increases in guarantee level does not always equal frequency of MTBF measurement. The TACAN, OMEGA Navigation Set, and the F-16 components contracts all provide for MTBF measurements every six months. The INS and AHRS contracts have a three-month provision, the first calculation to occur six months after government acceptance of the first unit. There is no analytic justification for these variances.

The following calculation captures most elements of MTBF formulas in use: total operating hours (TOH) during the measuring period divided by the total number of failures[1] during the measuring period. The numerator of the equation is usually assumed to be the same for all installed LRUs and SRUs and is calculated from elapsed-time-indicators (ETIs) built into the unit.[2] When subunit MTBFs are guaranteed, the denominator for the expression corresponding to each subunit is that subunit's total failures during the specified period.

Current contracts obviate the need to check each ETI at the end of each measurement by including a formula for estimating TOH from data on returned units only. Average operating time per day times number of days in the measurement period times average number of installations over the measurement period equals TOH.

In the F-16 program, FLU MTBF will be measured on Air Force aircraft only, although required corrections will be made to both Air Force and European Participating Governments (EPG) FLUs.

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[1]Generally, even unverified failures are included for purposes of arriving at MTBF, but not excluded failures.

[2]In the TACAN set, the ETI is on the Receiver/Transmitter unit; in the INS, it is on the Internal Navigation Unit; in the OMEGA Navigation Set, it is on the Receiver/Processor unit. In the AHRS, however, ETIs are installed on each LRU (SRU times are then calculated from the applicable LRU reading). By implication, the F-16 ETIs are on each FLU on USAF aircraft only.

Early Termination of Obligations

Under one contract, the contractor can completely fulfill the obligation of the guarantee before the warranty period ends. The TACAN contract provides that the guarantee obligation (but not the warranty obligation to repair or replace failed units) terminates when two consecutive measurements yield MTBF values that equal or exceed the final MTBF goal, although in no event will the obligation terminate earlier than 39 months after the contract award. The contract award date was 16 July 1975 and the warranty period began 1 May 1976. Thus the guarantee obligation may terminate only 29 months after delivery of the first production unit. This is indeed likely because data for the first 11 months reveal an MTBF of 771 hours (rather than the initial guarantee level of 500 hours and the final guarantee level of 800 hours).

FINAL OBSERVATIONS

A reliability improvement warranty consists of many important contractual provisions, each of which can be defined and constructed in various ways. An experiment such as the trial use of RIWs can teach the relative merits and drawbacks of alternative constructions. This opportunity is lost if important terms are varied indiscriminately. The present experiment poses such a danger: terms such as warranty period, penalties, and MTBF calculation frequency vary widely with little apparent analytic justification. As a result, it will be difficult to identify preferred alternatives because of the excessive number of variables, considering the sample size. The absence of closely monitored control groups compounds the problem.

III. COMMERCIAL AND DOD WARRANTY EXPERIENCE

INTRODUCTION

A reliability improvement warranty is one of a long line of techniques and methods designed to protect the services from systems with poor reliability. Mentioning some of the others and noting their weaknesses and differences is helpful in understanding the special nature of the RIW.

One way to influence an item's reliability is to fashion the design specifications so the resulting product is "better built" (through stricter materials specifications, for example) or less likely to "fail completely" (through requirements for more redundancy, for example). This approach generally increases the cost of producing an item (acquisition cost) and injects the service deeply into the design process, often overburdening designers with constraining limitations. "Enforcement" is typically limited to the requirement that the item pass certain reliability related acceptance tests, which usually mark the end of contractor responsibility. The critical difference in the warranty concept is its built-in provision for continued contractor responsibility for reliability after delivery and acceptance of his product.

A contractor maintenance arrangement involves the contractor in the support of his product but, inasmuch as it is usually based on a cost-plus contract, it really does not shift responsibility (in terms of who bears the costs of disappointingly low reliability) away from the service. It is too simplistic, however, to limit the difference between a warranty, which is a fixed-price contract, and a conventional contractor maintenance contract to the fixed-price/cost-plus distinction. Another important characteristic of the RIW concept is that it is intended to be negotiated before design and development are completed,[1]

[1]This has been tried only in the F-16 warranty programs, however.

so the contractor can ameliorate the design and engineering in response to the warranty's incentive feature.[1]

The RIW concept *is distinctive as a* "reliability technique" in that it involves the contractor during the support phase of his product's life, seeks to shift at least some of the reliability risk to him, and is introduced in the transaction early enough to allow responsive design and engineering improvements. It is actually an extremely ambitious concept *with two distinct beneficial goals.* On the one hand, it promises to shift risk so that the service no longer entirely bears the cost of compensating for reliability shortfalls--actually an insurance device. On the other hand it promises that the actual reliability of an item will *improve* compared with a nonwarranty counterpart. This poses a difficulty for evaluation of the concept because an RIW can succeed in its first promise yet fail in its second. That is, actual reliability improvement is irrelevant to successful shifting of risk,[2] which may in turn be a worthwhile objective whether or not reliability improvement is sought or even achievable. These objectives must be thought of separately.

There is little doubt that the RIW's foremost goal is contractor motivation to improve reliability. However, analysis of completed military warranty programs (see below, pp. 43-52) does not clearly establish that RIWs have been successful. This section examines the warranty experience in commercial environments, the original model for

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[1]This has not worked so neatly in practice. See C. David Weimer and Paul E. Palatt, *The Impact of Reliability Guarantees and Warranties on Electronics Subsystem Design and Development Programs*, Institute for Defense Analysis, S-483, October 1976. This study examined 11 electronic subsystems, representing the three major services. It concluded that "warranty options are presently not providing strong design and development incentives for achieving improved operational reliability, and that while warranty options have captured contractor management attention, more effort could be expended during development to achieve the warranty objectives."

[2]The test of the "risk-shifting" aspect of the RIW concept is whether the RIW is in practice rigorously enforced or subject to loss-or-risk-dampening modifications of terms (as traditional incentive contracts have been). On this latter point, see Alexander, in Johnson et al., R-2069-NSF.

the military warranty, for a similar warranty-reliability improvement link. The examination is preceded by a discussion of the RIW's general relationship to commercial and other warranties used by the military and is followed by a look at actual DoD warranty experience.

CONTEXTUAL CONSIDERATIONS

General Commercial Warranties

Warranty law is a subset of the larger area of sales law. Consequently, warranties are found in commercial transactions that range from property sales to consumer goods sales. As a result of a common law tradition in a federalist structure, sales law development was not uniform. In 1906 the National Conference of Commissioners on Uniform State Laws proposed the Uniform Sales Act, which was adopted by 37 states in 1950. In that Act may be found the modern foundation for warranty law.

The Uniform Sales Act has been replaced by the Uniform Commercial Code (UCC), which was promulgated in fall 1951 by the National Conference of Commissioners on Uniform State Laws and the American Law Institute. The UCC integrates the various uniform laws (Negotiable Instruments, Warehouse Receipts, Sales, Bills of Lading, Stock Transfer, Conditional Sales, and Trust Receipts) into a single broad subject of commercial transactions and has been adopted by 51 jurisdictions, including 49 states. Since the *Noonan Construction Case*[1] in 1963, the UCC has been used to resolve government contract disputes.

The UCC recognizes two major types of warranties, express and implied. As the term suggests, an *express warranty* is any affirmation of fact or promise made by the seller to the buyer and relating to the goods. It becomes a part of the bargain.[2] An *implied warranty* is one the law derives by implication or inference from the nature of the transaction or the situation or circumstances of the parties. The two most common implied warranties are the *implied warranty of merchant-*

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[1] ASBCA No. 8320.

[2] UCC § 2-313.

ability,[1] which warrants that the article sold shall be of the general kind described and reasonably fitted for the *general purpose* for which it is sold, and the *implied warranty of fitness for a purpose*,[2] which warrants that the goods sold are suitable for the buyer's *special purpose*. In general, warranties, whether expressed or implied, are construed as consistent with each other and as cumulative unless such construction is unreasonable, in which case the intention of the parties shall determine which warranty is dominant.[3]

DoD Warranties

The Armed Services Procurement Regulation (ASPR) permits the DoD to use warranties.[4] The Chief of the Purchasing Office must generally approve warranty use, and such approval must take into consideration the nature of the item, the cost of the warranty, administration (enforcement) of the warranty, and trade practice. Although the concept seems simple and straightforward, its application by the government is complex and confusing. For example, enforcing a supply contract warranty might involve looking at the ASPR provisions on Inspection Clauses, Warranty of Suppliers Clauses, Correction of Deficiency Clauses, Limitation of Liability Clauses, the UCC, and applicable case law. In fact, *The Report of the Commission on Government Procurement* stated that the warranty[5]

> problem is further complicated because post-acceptance Government remedies are provided for in so many different standard clauses and are stated to be "non-exclusive"; that is they are merely remedies in addition to whatever other remedies may exist under law.

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[1]UCC § 2-314.

[2]UCC § 2-315.

[3]UCC § 2-317.

[4]ASPR 1-324.

[5]*Report of the Commission on Government Procurement*, Washington, D.C., 1972, Vol. 4, p. 95.

Warranties under the ASPR are also distinguished from warranties in the commercial world in that, except for construction warranties, warranties are usually express--no implied warranties are usually attached to government procured items. ASPR 1-324.4(a) states, "When express warranties are included in contracts (except contracts for commercial items) all implied warranties of merchantability and fitness for a particular purpose shall be negated...." In addition the Standard Inspection Clause says, "Except as otherwise provided in this contract acceptance shall be conclusive except as regard to latent defects, fraud or such gross mistakes as amount to fraud."[1] In other words, the inspection clause can invalidate any implied warranty even though it is not expressly negated.

Government express warranties can be further categorized into "specification" or "performance" warranties. In a specification warranty, "The contractor warrants that *at time of delivery* all supplies furnished under this contract will be free from defects in material or workmanship and will conform with the specifications and all other *requirements of the contract*."[2] In a performance warranty, the contractor warrants that his item will perform its designated function, be adequate for its intended purpose, and maintain the required level of performance during the warranty period. (Actual figures for the types of warranties used by the DoD are not available, but a recent study of warranty usage in the Army found that 71 percent of the warranted contracts in their survey were specification warranties and 29 percent were performance warranties.)[3]

Reliability Improvement Warranties

The current definition of a Reliability Improvement Warranty (as stated in a 1977 proposed USAF ASPR Supplement) is:

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[1] ASPR 7-103.5.

[2] ASPR 7-105.7.

[3] E. Beeckler and H. Candy, "Analysis of AMC's Use of Warranties," Army Procurement Research Office, U.S. Army Logistics Management Center, June 1975.

> [A] provision in a fixed-price or fixed-price-incentive acquisition contract in which for a fixed price...: (i) the contractor is provided with the monetary incentive to improve the production design and engineering of the equipment throughout the period of the warranty to enhance the field/operational reliability and maintainability of the system/equipment; and (ii) the contractor agrees to repair or replace (within a specified turnaround time) all equipment that fails (subject to specified exclusions if applicable) during the period of the warranty.

This definition represents a culmination of 13 years of discussion and evaluation of the RIW concept within DoD. Yet the proposed ASPR change is only for the purpose of allowing *trial* applications of the concept. Nevertheless, in recent years the RIW concept has picked up momentum in the DoD's procurement activities. The RIW is often discussed as a "solution" to a number of problems that have classically plagued DoD procurement, such as cost control, reliability, maintainability, operational readiness, and contractor motivation. Although these problems are interrelated and their solutions not necessarily inconsistent, a procurement device that simultaneously addresses all these ills may create confusion when defense policymakers establish priorities among its multi-faceted capabilities.

The reliability improvement warranty is a type of performance warranty. Although the RIW concept may include contractual provisions not explicitly used before in other performance warranties, the motivations, incentives, benefits, and objectives in an RIW are present to some degree in most performance warranties. What is different is the application of this type of performance warranty to military avionics procurement and an increasing belief that the RIW uniquely motivates contractors to behave a certain way. What may also be new is the possibility of increased buyer control, resulting from a more explicit contractual arrangement. Means other than the RIW can, of course, also increase buyer control.

COMMERCIAL WARRANTY EXPERIENCE

Consumer Products

There is one important difference between the commercial and military buyer. The retail consumer's bargaining power, based partly on the extent and quality of his information, is much less than that of the military buyer. Quite naturally, the retail buyer (unlike the military buyer) needs greater assurances, which leads to a greater use of warranties, because the retail buyer probably knows little about the product and has little control over the seller's quality. In contrast, the military buyer has considerable bargaining power, knows the product quite well, and in fact actively participates in the development and production of the item. This crucial difference limits the utility of commercial experience as a basis for the military use of warranties. Nevertheless, the military's use of warranties to motivate contractors to improve their products' reliability has often been justified on the basis that (1) consumer product warranties have provided the consumer with a more reliable or higher quality product, and (2) warranties shift the risk of repair or replacement costs to the manufacturer. Both assumptions are generally incorrect.

Consumer goods warranties have actually had a very poor record from the consumer's perspective. Generally they have been used as a *promotional device* to increase sales and market share or as a *protective device* to limit liability through exclusions and disclaimers.[1] In either case, warranties serve the seller's interests, not the customer's.

One good example of the use of promotional warranties is provided by the automotive industry. Before 1960, all car makers granted a three months or 4,000 miles warranty to consumers and a concealed one

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[1] J. G. Udell and E. E. Anderson, "The Product Warranty as an Element of Competitive Strategy," *Journal of Marketing*, Vol. 32, October 1968, pp. 1-8; G. Fisk, "Systems Perspective on Automobile and Appliance Warranty Problems," *The Journal of Consumer Affairs*, Vol. 7, No. 1, Summer 1973, pp. 32-54.

year or 12,000 miles warranty to dealers.[1] Ford's marketing people thought that they could attract more customers, at almost no extra cost, by offering the dealer warranty directly to consumers. Other car makers immediately copied this move, nullifying competition on that basis.

In 1962 Chrysler extended its warranty to five years or 50,000 miles on the power and drive train, and the other auto makers offered two year warranties for the entire car. This differential remained until 1967 and was generally believed to have been a major factor in improving Chrysler's market share 67.7 percent (from 9.6 percent in 1962 to 16.1 percent in 1967), doubling its sales volume (from 667,000 cars in 1962 to 1,343,000 cars in 1967), and tripling its net income.[2]

For the 1967 model year, the auto makers matched Chrysler's warranty. This lasted until 1971, when all domestic car makers reduced their warranties to one year or 12,000 miles. They found their promotion abilities better than their warranty coverage abilities. An FTC report concluded:[3]

1. Quality control and warranty performance were declining.
2. The industry deliberately oversold its improved warranty in the 1960s, creating the impression that "higher levels of engineering and manufacturing skill" had overcome the complexity of the automobile.
3. Warranty extensions had no correlation with quality or developments in engineering and manufacturing.
4. The industry ran one ad after another emphasizing warranty as a proof of a better made car.

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[1] A. A. Strod, "An Investigation, Using Computer Simulation of Model of Product Warranty Effect on Operating Income," Ph.D. dissertation, Syracuse University, June 1975; T. S. Glickman and P. D. Berger, "Optimal Price and Protection Period Decisions for a Product Under Warranty," *Management Science*, Vol. 22, No. 12, August 1976, pp. 1381-1390.

[2] Strod (1975), p. 26.

[3] "Staff Report on Automobile Warranties," Federal Trade Commission, 1968.

Some car makers admitted their estimation errors. In December of 1966 Ford Motor Co. estimated that their 1967 model year extended warranty would cost them $79 per car. In July 1970, Ford reported that their 1967 model year warranty cost would actually exceed that estimate by over 50 percent ($120 per car). At that time, there was a substantial increase in warranty costs. The total Ford outlay to dealers for warranty costs between 1966 and 1967 increased by $130 million. For General Motors the increase added $200 million to costs; for Chrysler, $80 million.[1] As a result, some car makers attempted to reduce their costs by limiting reimbursements to dealers. In one case, the dealers sued the auto maker because it had advertised the 1967-69 five year warranty "without regard to its own quality control of its manufacturing process, and further without regard to the inadequate number of trained mechanics available for employment in automobile dealerships."[2] In summary, the extended, RIW-like auto warranty has generally not resulted in a more reliable or higher quality product. Its use has been mostly promotional.

Turning to the use of the warranty as a *protective* device, the President's 1969 Task Force Report on Appliances, Warranties and Services concluded, "The majority of the major appliance warranties currently in use contains exceptions which are unfair to the purchaser and which are unnecessary from the standpoint of protecting the manufacturer from unjustified claims or excessive liability."[3]

A supporting congressional study[4] found that the exemptions and disclaimers that producers used in limiting their legal obligation fell into the following categories:

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[1] R. A. Moellenberudt, "An Analysis of the Effects of the Product Warranty on Selected Companies in the General Aviation Industry," Ph.D. dissertation, University of Nebraska, Lincoln, 1973.

[2] Quoted in "Some Variable Costs of Ownership: Repairs, Insurance, Warranties," *Consumer Reports*, April 1970, p. 202.

[3] Reported in the House Interstate and Foreign Commerce Committee, Subcommittee on Commerce and Finance, Staff Report on *Consumer Product Warranties*, September 1974.

[4] Ibid.

1. Transportation and shipping costs and/or serviceman's travel charges excluded.
2. Home use only--other uses excluded.
3. Filters, plastic, and/or glass parts excluded.
4. Consequential damages excluded.
5. Disclaimer of implied and all other warranties.
6. Limited to parts only or to specific parts.
7. Warranty registration card required.
8. Void if serial plate defaced.
9. Special appliances excluded.
10. Opinion of the seller governs.
11. Valid for original purchaser only.

Analogous exemptions and disclaimers are to be found in the RIWs, particularly in the contract clauses describing failure exclusions (Sec. II).

Consumer warranties have worked so poorly that Congress passed the Magnuson-Moss Warranty Act in 1975[1] to assure the consumer some warranty protection through Federal Trade Commission monitoring of warranty practices.

The consumer product warranty experience does not substantiate a warranty's ability to protect the buyer or produce a better product. Contrary to the lessons offered by commercial experience, the DoD is using warranties to expand contractor liability and induce quality in product design.

Commercial Airline Avionics

As with consumer products, the use of warranties on commercial avionics equipment has been cited often as a basis for the use of RIWs by the military, particularly since one study concluded that RIWs in commercial avionics procurement produce higher equipment reliability.[2]

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[1] P.L. 93-657, 15 U.S.C. 2301 (1975).

[2] H. Balaban and B. Retterer, "The Use of Warranties for Defense Avionics Procurement," ARINC Research Corporation, RADC TR-73-249, June 1973. See also P. Klass, "New Data Yield Clues to Reliability," *Aviation Week and Space Technology*, February 13, 1967.

That report compares military and airline MTBFs for similar equipment (see Table 8). At first sight, it appears that the airline MTBFs are higher, even for the last three equipment classes where the comparisons are between identical units. Yet the equipment is similar only in function, not necessarily in performance. The higher performance standards for the military may decrease reliability. For example, although an inertial navigation system for a commercial airliner and a troop transport may be similar, the military demands greater precision or imposes greater environmental loads. A commercial transport aircraft inertial navigation system need only be accurate enough to keep the airplane in a 20 X 25 mile lane box until radar picks it up near its destination point and vectors it in. A troop transport would require much greater accuracy because it might have to find its destination point without the aid of ground radar. Likewise, the military inertial navigation system is subjected to a greater environmental load in that the troop transport requires a faster warm-up time because its use is not always scheduled, whereas the warm-up time for a commercial system is not critical because it can be turned on long before its scheduled use.

Reliability differences may also be due to one or more of the following factors: procurement practices, operational environment, maintenance environment, equipment design and complexity, and data collection and retention procedures (see Table 9).[1] Furthermore, it is not possible to quantify the degree to which these factors affect observed MTBF. Nevertheless, that study concluded, "The extensive airline use of warranty provisions in [commercial] avionics procurement contracts would certainly exert a positive influence on initial reliability achievement and on reliability growth."[2]

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[1]An illustration of the difference in data collection and retention practices can be found in the Klystron electron tube warranty program. The value of that warranty was destroyed when the Air Force incorrectly coded the item as a "throwaway." When removed by service personnel, the item was discarded instead of being returned to the contractor for repair or replacement.

[2]Balaban and Retterer (1973), p. 13.

Table 8

SOME COMPARISONS BETWEEN AIRLINE AND MILITARY AVIONICS RELIABILITY

Equipment	Source (M = Military)	Operating(O) or Flying(F) Hours	Number of Removals	Number of Failures	MTBR	MTBF
Weather Radar						
RDR-1F	Airline A	438,480(O)	1,307	390	335	1,124
RDR-1F	Airline C	NA	NA	NA	555	1,157
AVQ-30	Airline B	186,810(O)	561	NA	333	666[a]
AN/APS-115	P-3C(M)	19,450(O)	295	149	66	130
Inertial Navigation						
Carousel	Airline B	326,500(O)	925	NA	353	706[a]
LTN-51	Airline Composite	360,720(O)	NA	361	450[a]	999
AN-ASN-84	P-3C(M)	35,900(O)	442	186	81	192
LORAN (A & C)						
345 & 700(A)	Airline B	182,460(O)	568	NA	322	644[a]
AN/APN-151(C)	RC-135(M)	9,600(O)	NA	94	51[a]	102
AN/APN-157(C)	C-141/HC-130H(M)	164,400(O)	NA	3,823	22[a]	43
HF Communications						
618 T-2	Airline B	228,400(O)	555	NA	412	824[a]
ARC-142	P-3C(M)	28,520(O)	608	160	47	178
UHF/VHF Communications						
RIA-41A	Airline B	326,530(O)	591	NA	552	1,104[a]
ARC-143	P-3C	37,430(O)	468	115	80	325
Automatic Direction Finder (Receiver)						
DFA-70	Airline Composite	647,270(F)	643	359	1,006	1,802
DFA-70	RC-135/WC-135(M)	30,150(F)	NA	141	107[a]	214
DFA-73	Airline Composite	38,500(F)	41	26	939	1,480
DFA-73	C-141/HC-130(M)	1,100,000(F)	NA	1,240	444[a]	887
Marker Beacon (Receiver)						
51Z-4	Airline Composite	570,300(F)	180	114	3,168	5,000
51Z-4	C-141(M)	506,670(F)	NA	184	1,376[a]	2,753
VOR Localizer (Receiver)						
WIL 806A	Airline Composite	NA	NA	NA	570	1,000
WIL 806A	C-141(M)	506,670(F)	NA	1,654	153[a]	306

SOURCE: H. Balaban and B. Retterer, "The Use of Warranties for Avionics Procurement," ARINC Research Corporation, RADC TR-73-249, June 1973, p. 12.

[a]Data not available. For gross comparison, estimate based on MTBR = 2 X MTBR.

Table 9

DIFFERENCES BETWEEN DEFENSE AND SPACE, AND COMMERCIAL PRODUCTS, IN THEIR DESIGN, USE, ENVIRONMENTAL SURROUNDINGS, STORAGE, AND MAINTENANCE

A. DESIGN OF PRODUCT

Designs usually are geared to the following objectives in order of priority:

DEFENSE AND SPACE	COMMERCIAL
1. Improved performance capabilities involving advancements in the state of the art	1. Simplicity of equipment to permit fool-proof operation
2. Continuous operation of equipment under extreme environmental and working conditions	2. Competitive performance capability
3. Extremely limiting space and weight restrictions	3. Lowest possible cost
4. Reasonable cost	4. Reasonable equipment life assuming normal use under average conditions
5. Possible long-time storage before initial use	5. Ease of maintenance
6. Design changes continue after production begins	6. Design is completed and frozen before production begins

B. USE OF EQUIPMENT

DEFENSE AND SPACE	COMMERCIAL
1. Moderate pre-purchase testing	1. Extensive pre-purchase testing
2. Normally used under the worst possible field conditions at extremes of temperature, etc.	2. Normally used under the best possible field conditions designed for the comfort of the user
3. Operated by people who have little or no motivation to "preserve" the equipment	3. Operated by people who are highly motivated to "preserve" the equipment either because of ownership or in the interest of job retention
4. Because simplicity of design usually is not a primary objective, operation of complex equipment is normally also surrounded with equal complexity. Operational training is normally inadequate and never keeps pace with design and resulting operation changes	4. Because the equipment was originally designed with ease of operation in mind, this plus the greater experience and training of operators make for fewer field problems.

(Table 9 continued)

C. ENVIRONMENTAL SURROUNDINGS

DEFENSE AND SPACE	COMMERCIAL
1. The location of ultimate field use of the equipment is rarely, if ever, known and designs must therefore make provision for extremes in temperature, humidity, equilibrium, vibration, maintenance and repair, etc.	1. The approximate location of ultimate equipment use is always known. If the same TV model is to be distributed for sale in Canada and the tropics, suitable adaptive changes are made in the products sent to different areas
2. Because of the ever-increasing need for greater economy in defense, there is an increasing desire for multiple usage of equipment--for example, aircraft suited to both land and sea warfare; communication equipment usable in aircraft, on the ground, and under the sea, etc.	2. Extremes in physical conditions of use, such as excessive vibration, etc., are rarely encountered

D. STORAGE

DEFENSE AND SPACE	COMMERCIAL
1. Many of the products purchased by NASA and DoD are for long-time storage before actual need and use. Damage sustained during this period of idleness is extremely difficult to isolate and distinguish from the causes of malfunction in later use. Mishandling during storage can be a major cause of later disfunction	1. On-the-shelf storage of commercial products before sale and use is of short duration

E. MAINTENANCE AND REPAIR

DEFENSE AND SPACE	COMMERCIAL
1. Frequently attempted by inadequately trained service personnel under adverse field conditions and with improper or inadequate facilities and tools	1. Usually performed by competent personnel under favorable shop conditions
2. Subsequent attempts to place the blame for equipment malfunction where it properly belongs are either difficult or impossible	2. Usually easy to determine whether malfunction of equipment was because of product failure or user abuse
3. The cost of improper maintenance and repair is exorbitant and the equally high cost of settling the responsibility for malfunction added to it make the enforcement of express warranties non-cost effective in the extreme	

SOURCE: Adapted from letter from CODSIA to Dr. Paul Arvis, Director, U.S. Army Procurement Research Office, U.S. Army Logistics Management Center, July 2, 1975.

This conclusion is not justified. Although there might be a correlation between warranties and an increased MTBF in commercial avionics, causality was not clearly established. In fact, it is questionable how strong the correlation between the warranty and increased MTBF actually is. If there is a correlation between the commercial avionics environment and a high MTBF, a correlation between the warranty and MTBF does not necessarily follow.

Even if we assume that the warranty caused an increase in MTBF, did that necessarily result in lower life-cycle costs (for the buyer)? The same study concluded that warranties represent just one factor in the airline procurement environment that tends to yield reliability and *life-cycle cost* values much more favorable than those of comparable military applications.[1]

It has never been shown that the airlines have more favorable life-cycle costs as a result of using a warranty. In fact, although recovered warranty claim figures are sometimes mentioned, no cost-benefit analysis has been done.[2] Thus, these figures are not useful except to show that some warranty claims were made and recovered.

The evidence is insufficient to support the assertions that the airlines have a higher MTBF than the military because of the warranty or that the warranty results in lower life-cycle costs in commercial avionics procurement. Therefore, the justification of warranty usage in the military on the basis of better MTBFs in commercial avionics is misleading.

COMPLETED DOD WARRANTY PROGRAMS

The extensive trial use of RIWs was prompted largely by the highly regarded use of warranties by commercial airlines and some favorable analysis of their potential for military application. Although the action coincided with considerable attention to the concept

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[1]Ibid., pp. 22-23.

[2]"The airlines have developed no standard by which to measure the cost-benefit derived from the use of warranty," Bizup and Moore (1976), p. B-4.

by both the Navy[1] and the Air Force,[2] actual DoD experience with warranties at the time was very limited.

Even today, information about actual warranty outcomes is limited. Available outcome data on the current trial warranty procurements are scarce and inconclusive. However, available data do permit examination of the three programs in which the warranty period has lapsed.

The Navy's 2171 Gyroscope

For practical purposes, the first item purchased by one of the military services under a warranty was the Navy's CN494A/AJB-3 Gyroscope (hereinafter referred to as the 2171 gyro--the contractor's nomenclature). The 2171 gyro was initially designed and produced by Lear Siegler, Inc. in the 1950s and was introduced into service with the A-4 and F-4 aircraft in the early 1960s. The item initially experienced disappointingly low reliability--a MTBF of 100 flight hours. In response, a product improvement/retrofit program was begun to devise and institute corrective design changes.[3] Within several years, the MTBF was improved to 246 flight hours. However, the Navy never became entirely self-sufficient in overhauling and repairing failed units. Because of the many returns, it retained Lear Siegler to handle spillover repairs.

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[1] See, e.g., Department of the Navy, Headquarters Naval Materiel Command, "Application of Failure Free Warranty Provisions," Memorandum dated 11 May 1973; Letter from Navy Materiel Command to Commanders of Systems Commands, "Trial Use of Reliability Improvement Warranties," 20 March 1974; D. J. Allen, *Application of Reliability Improvement Warranty (RIW) to DoD Procurements*, Master's thesis, Naval Postgraduate School, March 1975.

[2] See, e.g., U.S. Air Force, DCS/Systems and Logistics, Directorate of Procurement Policy, *Interim Guidelines, Reliability Improvement Warranty (RIW)*, July 1974; ARINC Research Corporation, *Preliminary Report on Warranty Data Needs, Selection and Evaluation Criteria*, 30 September 1974; P. Dunn and A. Oltyan, *Evaluation of Proposed Criteria to be Used in the Selection of Candidates for Reliability Improvement Warranties*, Master's thesis, Air Force Institute of Technology, January 1975; ARINC Research Corporation, *The Development and Analysis of RIW and COD Provisions for the Air Combat Fighter (ACF) Aircraft*, February 1975.

[3] See United States Navy, Aviation Supply Office, *Case Histories of LCC [Life Cycle Costing] Procurements*, April 1974.

In 1967, using the data and experience gained in this role, Lear Siegler proposed a warranty arrangement (then called a "failure-free warranty") for the repair of a fixed gyro population of 800 units for 1500 operating hours per unit or five years, whichever occurred first.[1] Overhaul and repair responsibility for the other 2400 units in the inventory remained unchanged.

The resulting warranty contract had the goal of increasing the warranted gyros' MTBF from 400 to 520 operating hours in three 20-month phases.[2] The first phase improvement to 400 hours was expected to result from planned updating of all 800 units to the then most reliable configuration. The second and third phase improvements to 480 and 520 hours were to come from processing improvements and engineering redesign resulting from failure analysis. The contractual performance that was called for differed in two significant respects from the warranty contracts in force. First, the contractor was obligated only to repair failed units. In this respect, the warranty was actually a type of fixed-price contractor maintenance contract for a subpopulation of gyros. Second, unlike the warranties featuring MTBF guarantees, the 2171 gyro warranty did not require corrective redesign and retrofit.

The interim reports on the warranty were generally favorable.[3] The 520-hour MTBF goal was achieved two years earlier (1971) than predicted. During the same period, the MTBF of non-warranted gyros improved to 442 hours.[4]

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[1] The warranty ended after five years but was extended two months.

[2] The pre-warranty MTBF was 246 *flying* hours. For purposes of the warranty this was converted to *operating* hours using a factor of 1.63.

[3] See, e.g., J. Harty, "A Practical Life-Cycle Cost/Cost of Ownership Type Procurement Via Long-Term/Multi-Year 'Failure-Free Warranty' (FFW) Showing Trial Procurement Results," in *1971 Annals of Reliability and Maintainability*, June 1971, pp. 241-251; O. Markowitz, "A New Approach: Long Range Fixed Price Warranty Within Operational Environments--For Buyer User," ibid., pp. 252-258; O. Markowitz, *Report on Analysis of FY 1973 Cost Saving Resulting from the FFW, Contract N00383-67-6-3101 in Lieu of a Commercial Overhaul Contract Alternative*, United States Navy, Aviation Supply Office, June 1973.

[4] Bizup and Moore (1976), p. 176.

Attribution of the reliability improvement and the better reliability of the warranted units to the warranty itself must proceed cautiously. Some of the improvement was likely due to the configuration updating and the processing improvements identified before the warranty. Lear Siegler's performance under the warranty included a continuous test program using laboratory units. Roughly 50,000 hours of testing provided data that directly influenced corrective design changes in warranted units.[1] To the extent that the warranty included a requirement for continuous testing, it could perhaps be credited with the improvement. Increased testing and modification based on the information generated has long been suggested as a salutory reform.[2] It remains to be seen whether requiring continuous testing independent of a warranty--that is, using some of the funds now invested in RIWs to finance additional testing and modification--could have produced a similar outcome while saving the administrative costs of the warranty. That possibility dilutes the force of the 2171 gyro warranty experience as a prescriptive model for further warranty application.

Whether the warranty approach saved the Navy money is also uncertain. A study prepared for the Navy Air Systems Command found that warranty costs at the end of the basic contract actually exceeded the probable costs of support without the warranty, but that after the two-month contract extension designed to compensate for earlier underutilization, the Navy realized costs savings from the warranty approach.[3] Independent recalculations in the course of this study revealed the differential to be much less than the Navy's calculation; in fact, after the period extension the warranty costs very slightly

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[1] ARINC Research Corporation Warranty Information Center, "Case Study of the 2171 Gyroscope," n.d.

[2] See, e.g., *Report of the Commission on Government Procurement*, Vol. 2, pp. 157-166; Robert Perry et al., *System Acquisition Strategies*, The Rand Corporation, R-733-PR/ARPA, June 1971.

[3] Bizup and Moore (1976), pp. 31-32 and Appendix A.

exceeded the predicted cost of the non-warranty alternative.[1] This difference is probably offset by the savings from reduced spares requirements made possible by the higher MTBF levels of warranted units (about 23 percent fewer spares in the case of the 2171 gyro RIW population), whatever the cause, and by the greater OR rates themselves.

The 2171 gyro had been redesigned several times and the contractor was experienced in servicing the fielded inventory. A substantial increase in testing and the information gained may have accounted for the greater MTBF improvement in the warranted gyros. The contract itself resembled a fixed-price maintenance contract (note the emphasis on repair), although admittedly one with an eye toward reliability growth (note the MTBF goals). The ambiguity of the outcome aside, the 2171 gyro warranty is a difficult one from which to generalize.

The Air Force's F-111 Gyroscope

The next major contract involved the gyroscope for the Air Force's F-111. The F-111 flight control gyro (SBK-11/A24G-26) was originally designed in the early 1960s by General Electric specifically for use in the F-111. The first 534 units were supplied by General Electric under a sole-source contract. After a review of FY 1969 program requirements the Aeronautical Systems Division of Air Force Systems Command concluded that the low reliability of the gyros necessitated a new procurement in a competitive environment. The Navy's gyro warranty provision inspired inclusion of a warranty requirement in the new F-111 gyro procurement. Lear Siegler, the supplier of the Navy gyro, won the competition for that procurement.

The contract awarded to Lear Siegler in January 1969 called for the purchase of 601 gyros, which were warranted against failure in that Lear Siegler promised to repair or replace any units that failed during the warranty period, ended by agreement of the parties in November 1976. There was no MTBF improvement guarantee or goal. The non-warranted, General Electric gyros were experiencing an MTBF of 681 operating hours.[2]

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[1] See Table 10 for the two calculations.

[2] Calculated from a measurement of 426 flight hours using a factor of 1.6.

Table 10

COMPARISON OF RIW AND PROBABLE NON-RIW COSTS, 2171 GYRO CONTRACT PERIOD AND EXTENSION: NAVY STUDY AND RAND CALCULATIONS

	No. of Units	Operating Hours (5 yrs., 2 mos.)	Average MTBF[a]	No. of Failures	Cost/ Failure	Total Cost
	(a)	(b)	(c)	(d)=(b)/(c)	(e)	(f)=(d)(e)
Naval Air Systems Command Study[b]						
RIW	800	1,020,000	518	1,969	$2,064	$4,065,000
Non-RIW	800	1,020,000	421	2,424	$1,545	$4,530,000
Rand Calculations						
RIW	800	1,020,000	459[c]	2,222[d]	$2,060[e]	$4,577,320[f]
Non-RIW	800	1,020,000	421	2,423[g]	$1,868[h]	$4,526,164[f]

[a] Assumes improvement was linear.

[b] Bizup and Moore (1976), Appendix A.

[c] Uses average MTBF, assuming improvement was linear.

[d] Calculated from Operating Hours ÷ Average MTBF (1,020,000 ÷ 459).

[e] Calculated by updating cost per failure figure (2014) for basic contract period:

$$\text{cost per failure} + \frac{\text{cost of warranty extension}}{\text{number of failures}} \text{ or } \left(2014 + \frac{101,000}{2222}\right).$$

[f] Calculated from No. of Failures x Cost/Failure.

[g] Calculated from Operating Hours ÷ Average MTBF or (1,020,000 ÷ 421).

[h] Calculated by updating cost per failure figure (1454) to reflect Engineering Change Proposals and other costs of improving MTBF of non-warranty units:

$$\text{cost per failure} + \frac{\text{cost of MTBF improvement}}{\text{number of failures}} \text{ or } \left(1454 + \frac{1,002,200}{2423}\right).$$

Although there was no guarantee, Lear Siegler's proposal indicated an expected improvement to 1494 operating hours.

The MTBF growth has fallen short of that projection. During October 1973 the warranted gyro population achieved a MTBF of 1214 operating hours. At the same time, the non-warranted units still in use demonstrated an MTBF of 749, the increase generally attributed to a variety of improvements initiated by Air Force Logistics Command. Since that date, the MTBF of the Lear Siegler gyro has steadily fallen: In October 1974, it was down to 1162; in July 1976, it had fallen to 995 operating hours. The difference in measured reliability levels cannot be traced to a warranty: Lear Siegler incorporated no major design changes during the warranty period.[1]

Several factors, other than measurement imprecision, may have accounted for the difference between the reliability levels of the warranted and non-warranted gyros. First, the warranted units were produced by a new manufacturer at a later date and as a result of a *competitive* (through formal advertising) source selection; these changes may themselves have improved reliability. Second, there was extensive additional failure mode testing conducted during one year before the warranty period. As in the 2171 gyro program, this augmented test regimen probably improved the item's reliability and could be duplicated even without a warranty.

The F-111 program itself was plagued by problems, many interfering with the expected operation of the warranty. The two most important factors were fewer units purchased and severe underutilization of the units that were purchased:

- The initial plans called for the purchase of 601 warranted units. The initial contract was influenced by cutbacks in the F-111 program and called for only 332 units. Additional revisions reduced the number to 128.

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[1]Lear Siegler did make one minor change: incorporation of a new bearing actuation to correct a directional gyro drift problem.

- When the warranty period ended, the operating hours of the warranted units were about half the expected amount. The underutilization was due to recurrent groundings of the F-111 fleet and delays in installations of the gyros. The warranty period began when the gyros were delivered to the Air Force; the F-111 prime contractor, General Dynamics, often installed them six months later.

The combination of these events had two important results. First, the ultimate cost per operating hour of the equipment was very high. Later contracts used special price adjustment provisions to address this problem. A more troublesome result, one not addressed by new contractual clauses, is the deleterious effect on the contractor's motivation to make changes. The few units in the field and the low rate at which they were used meant that a representative failure distribution was not achieved until the warranty period was 80 percent complete. Lear Siegler justifiably chose not to make any investments in engineering improvement: Its remaining period of responsibility for the reliability of its gyros was not very long, and the prospect for recoupment of its investment was reduced by the small number of units in the field. A third result was that Lear Siegler failed to meet the turn-around time goal (TAT goal was 45 days; actual TAT was 90 days).

The Navy's APN-154 Radar Transponder

The APN-154 is an airborne X-band Radar Transponder that extends the range of surface radar and identifies specifically equipped airborne targets. It was first produced (by United Telecontrol) in 1965 and has been used in such aircraft as the A-6, A-7, F-4, F-14, CH-46, and CH-53. Installed in fixed wing, jet, and propeller-driven aircraft, as well as rotary-wing aircraft, the equipment must operate in various mechanical and thermal environments. Early reliability tests found many failures (the transponder had an MTBF of 534 operating hours in 1968) were environmentally related. For example, in one case, the transponder was mounted adjacent to the jet exhaust tail cone. During normal flight and ground operation, the equipment temperature

was maintained well within its limit, but in extended jet engine ground operation, as might occur during engine test or an unusual taxi situation, the equipment temperature would rise more than 30°C above the maximum limit, causing equipment failure. Design changes in the heat sink and component part selections provided satisfactory transponder operation at the higher temperature and an unspecified increase in MTBF.

In early 1972, United Telecontrol undertook a company-funded study to develop longer-lived replacements for the local oscillator and magnetron assembiles. These two thermionic assemblies, produced before solid-state devices of sufficient reliability were affordable, were the major causes of earlier failure: They contained cathodes that limited assembly life to about 250 hours. The study produced a suitable solid-state replacement for the local oscillator design, requiring only minor power supply modifications. Although the search for a solid-state magnetron assembly was not successful, the contractor discovered that the magnetron's life could be extended by redesigning the existing cathode structure.

United Telecontrol then submitted an unsolicited proposal to the Navy to substitute the solid-state oscillator and modify the magnetron. This proposal was combined with provisions for warranty coverage (known then as a "failure-free" warranty) and negotiated as an ECP to the existing production contract.

The warranty went into effect in January 1973. It covered 218 transponders for 26 months or 1000 operating hours. (The magnetron assembly was covered for 24 months and 500 hours.) Data collected (under test conditions) at the close of the warranty period indicated that the MTBF had increased to 2025 hours, a seemingly striking success for the warranty application.[1]

No evidence links the warranty and the reliability improvement. By United Telecontrol's admission, the improvement resulted from the lessons learned from extensive operational use in a number of fixed

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[1] Gus Schmelling, "FFW Experience with the APN-154 Beacon," *Proceedings of Aviation Supply Office Failure Free Warranty Seminar*, Philadelphia, Pa., December 1973, p. 42.

and rotary-wing aircraft and the great improvement in semiconductor reliability during the period. The warranty appears to have come along in time to receive credit for the considerable test and redesign effort expended before its incorporation into the contract.

IV. CONCLUSIONS

The major applications of the RIW have begun only recently; definitive observations on their success or failure naturally must await better data. As an interim effort, this report has sought to (1) reassess the lessons drawn from commercial warranty experience; (2) summarize the outcomes of the three completed DoD warranty contracts; and (3) survey and describe, on a cross-program basis, the substantive terms of existing contracts.

When the Office of the Secretary of Defense requested RIW trial applications in August 1974, military warranty experience was scant, but commercial experience was widely regarded as promising. However, from the buyer's perspective, commercial experience does not alone justify optimistic expectations for RIWs. Consumer product warranties have usually been either promotional or protective--i.e., they have either been marketing tools or devices to limit liability. They rarely improve product quality. Commercial airline avionics, which usually carry warranties, appear at first sight to be generally more reliable than similar equipment used by the military services. However, there are too many differences in the commercial and military worlds--e.g., in definitions, mission requirements, operating and support environments and data systems--to credit the warranties with being the major cause of commercial products' improved reliability.

Although completed DoD warranty programs exhibited improved reliability, there is no conclusive evidence that the warranty was a major factor. The improvement of one item is traceable not to the warranty but to *pre-warranty* and externally generated component technology advancements. Another improvement may have been obtainable through effective use of increased testing apart from the warranty program, and perhaps at less cost. The third improvement was due to several factors, the most important of which was not the warranty but rather a change in contractors. Nevertheless, examination of these programs does permit the following observations:

- o Modification after some operational use or appropriate operational testing is almost always desirable to take advantage of field experience and advances in component state of the art and can be promoted without a warranty.
- o Implied in the above statement is the worth of schedule flexibility to allow incorporation of test data in the subsequent development and production process.
- o To the extent that modification is envisioned or desired, the contractor should be involved in the initial overhaul and repair activities to improve its ability to formulate product improvements.
- o Because the prospect for reliability growth is dimmed by program quantity reductions and underutilizations, RIWs should not be applied to programs subject to extreme quantity or utilization uncertainty.

Several aspects of the current trial applications diminish the likelihood that they will yield conclusive evidence on the relative value of RIWs. Because an RIW is a collection of complex contractual terms, one of the opportunities an experiment like this affords is identifying preferred contractual constructions. This opportunity may be lost if, as in the case of the present set of contracts, important terms and penalties vary widely and not in accordance with a conscious plan for evaluation. Two other facts make the variation of terms disturbing: the absence of adequate "control" groups and conditions, and the continued consideration of new applications. The design of the experiment should be improved by at least three actions:

- o *Reduce the variation in contractual terms and penalties.* A first step is the careful development of hypotheses about desirable constructions so that variations can be consciously and systematically devised to test them.
- o *Develop better control conditions.* The same difficulty in isolating the warranty as the cause of the reliability improvement in the completed DoD programs is likely to plague the analysis of current programs.

- o *Bound the experiment.* Rather than beginning new trial warranty programs for an indefinite period, the experiment, which has a discernible birthdate, should have a finite number of trial programs. This would permit better assessment of interim data and prompt final evaluation.

The experiment is also hampered by deficiencies in a number of associated methodologies. For example, both the contractor and the services have limited ability to confidently price warranty and non-warranty alternatives. Methods for reliability measurement and prediction are similarly imprecise. Improvements in these areas would enhance selection, monitoring, and evaluation of warranty programs.

Evaluation of the warranty concept will be further complicated by the multiple, independent objectives that an RIW can serve and the failure to establish priority among them. These objectives include:

- o *Reliability improvement.* This objective is attained if the contractor is motivated to change his behavior so that the item he produces is more reliable.
- o *Life-cycle cost reduction (cost shifting).* This objective is attained if the service "makes a good deal"--i.e., if the price of the warranty coverage is less than the price of alternative logistics support arrangements and if the warranty does not cause offsetting increases in acquisition cost or support cost after the warranty period (or during transition out of it).
- o *Insurance (risk shifting).* This objective is attained if the service and the contractor execute a binding indemnification contract, enforceable in court.

Any one of these objectives can be attained without either of the others. That is (assuming the ability to establish cause and effect), a warranty might induce reliability improvement but increase life-cycle cost; or, it might reduce life-cycle cost but have no effect on reliability; or it might fail either to reduce life-cycle cost or

improve reliability but instead might represent a binding obligation on the part of the contractor to provide interim product support. The military must arrive at a consensus on the priority of these objectives to create a framework for evaluating RIW data and formulating RIW policy.

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